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Analysis of Oceanic Precipitation before the Satellite Era

Thomas M. Smith[1, 2], Phillip A. Arkin[2], and Li Ren[1]

[1]*Cooperative Research Program, NOAA/NESDIS/STAR*

[2] *Earth System Science Interdisciplinary Center / Cooperative Institute for Climate and Satellites-Maryland*

1. Introduction

Satellite-based analyses are critical for climate analyses because of their ability to sample globally with much higher frequency than is possible using in situ observations. The satellite measurements most important for long records of global precipitation include those from infrared and microwave instruments. The Global Precipitation Climatology Project (GPCP, Adler *et al.* 2003) combines bias-adjusted satellite-precipitation estimates with the available in situ measurements to produce a monthly global analysis beginning 1979. Before 1979 satellite data are not adequate for quantitative global analysis and here we refer to 1979 as the beginning of the satellite era.

Before the satellite era there were many island and land in situ precipitation measurements, allowing for a fairly comprehensive land analysis back to 1900 or earlier. However, there are almost no oceanic precipitation measurements for that period. Oceanic precipitation is a critical component of the Earth's hydrologic cycle because the oceans cover roughly 70% of the surface and because oceanic variations influence those over land. A better understanding of oceanic precipitation for a period longer than the satellite era would improve understanding of global climate variations, including the influence of global temperature changes on precipitation.

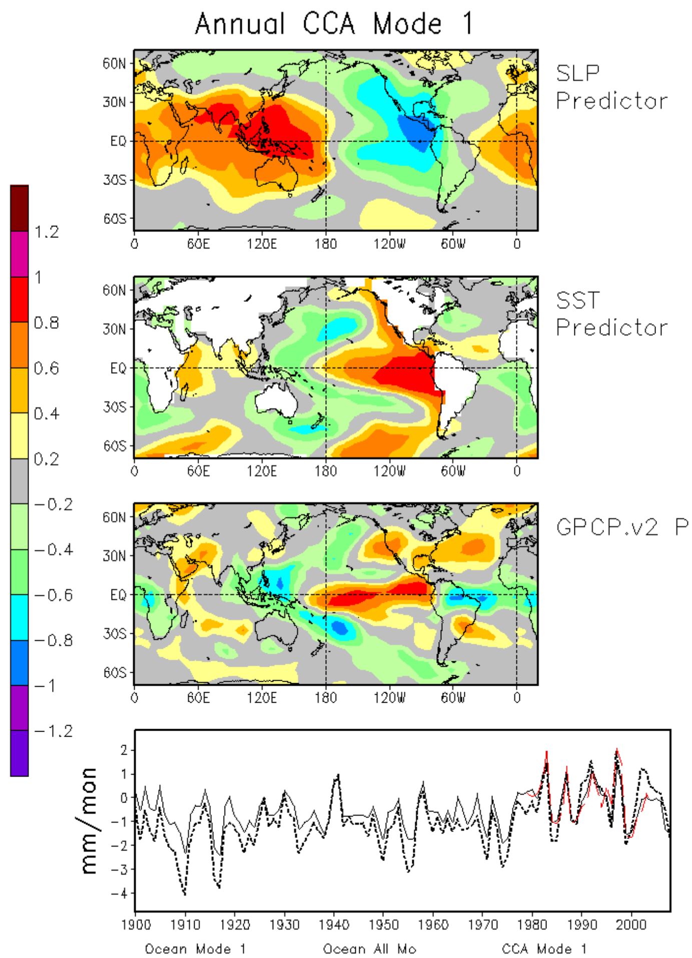

Fig. 1 First CCA spatial predictor and GPCP predictand spatial pattern (upper 3 panels) and the CCA and reconstruction time series for ocean areas for the 1st and all 8 CCA modes used (lower panel).

Reconstructions of global precipitation have been developed. Reconstructions are extended analyses of relatively sparse data using statistics produced using data from a shorter but densely-sampled period. The GPCP data provide roughly 30 years of data that have been used to analyze global precipitation beginning 1900. A series of reconstructions were produced by the authors, with knowledge gained from each used to improve subsequent reconstructions (Smith *et al.* 2008, 2009, 2010, 2012). Here we give a summary of some aspects of the ocean-area precipitation analysis and how reliable it is in the pre-satellite period.

Correspondence to: Thomas M. Smith, NOAA/STAR/SCSB and CICS/ESSIC University of Maryland, 5825 University Research Court, Suite 4001, College Park, MD 20740; E-mail: tom.smith@noaa.gov.

2. Results

The most recent reconstruction method begins with a canonical correlation analysis (CCA) to estimate annual precipitation anomalies from annual SST and SLP predictors. That step was found to better represent annual large-scale oceanic variations. The first CCA mode shows that much of the variance from this analysis is ENSO like, but including additional modes enhances multi-decadal variations in the ocean-area CCA (Fig. 1). Ocean area CCA output is combined with annual gauge anomalies and used to estimate annual global anomalies by fitting those data to a set of spatial modes.

The spatial modes used to combine annual CCA and gauge data are annual Empirical Orthogonal Function (EOF) covariance modes. Modes not adequately sampled would be removed, although including CCA data means that under-sampling of modes never occurs. As an example, the first (main ENSO) annual mode is shown along with the time series from GPCP, from GHCN gauges alone, and from combined gauge and CCA inputs (Fig. 2). Note that most of this mode's variations can be reconstructed for the historical period using either gauges alone or gauges combined with CCA output, although the multi-decadal signal is a little stronger when CCA output are included.

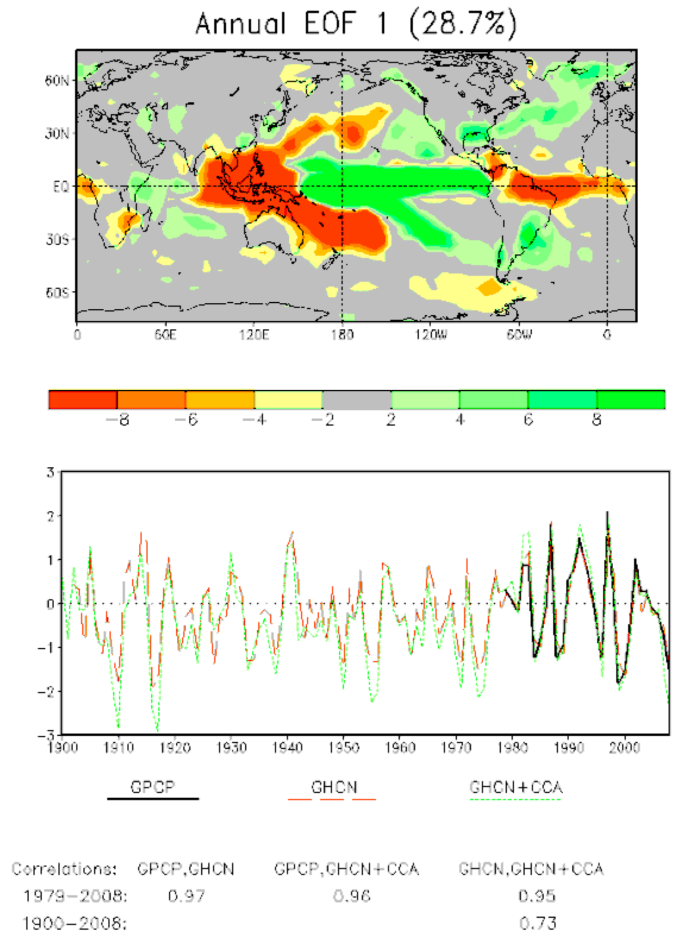

Fig. 2 First covariance EOF of GPCP annual anomalies and the time series from GPCP along with reconstructed time series for gauges alone (GHCN) and gauges + CCA over ocean areas. Correlations for the time series are also given.

The annual estimate is adjusted by analyzing monthly anomaly increments from the annual average. For this step we use gauge monthly anomaly increments and a set of monthly increment spatial modes. The sum of annual and monthly increments defines the monthly reconstruction. In some versions the monthly gauge anomalies are statistically re-injected to reduce differences from gauges in regions where gauges are available.

Cross-validation analyses are used to help show the reliability of the analysis in historical periods. For these test analyses the GPCP data are analyzed using the reconstruction method. Data for the analysis year are removed for computing statistics and data are subsampled using historical sampling masks. Comparisons to the full GPCP give an indication of reliability. An additional test of the reconstruction reliability is the reconstruction of model output from a reanalysis model that incorporates observed SST and SLP. Results from both of these tests show that the reconstruction is capable of resolving large scale oceanic variations on interannual and longer time scales, but it is less reliable for small regions and shorter time scales.

Global-average results were compared to CMIP5 coupled model output by Ren *et al.* (2013). Although there is a lot of spread among the various models, the global model mean is similar to the reconstruction (Fig. 3). The reconstruction is more variable than the model mean since interannual variations are filtered out of the mean. Over the oceans both the model mean and reconstruction indicate a gradual increase until about 1960, followed by a flat or slight decrease period until about 1980, followed by an increasing global averages.

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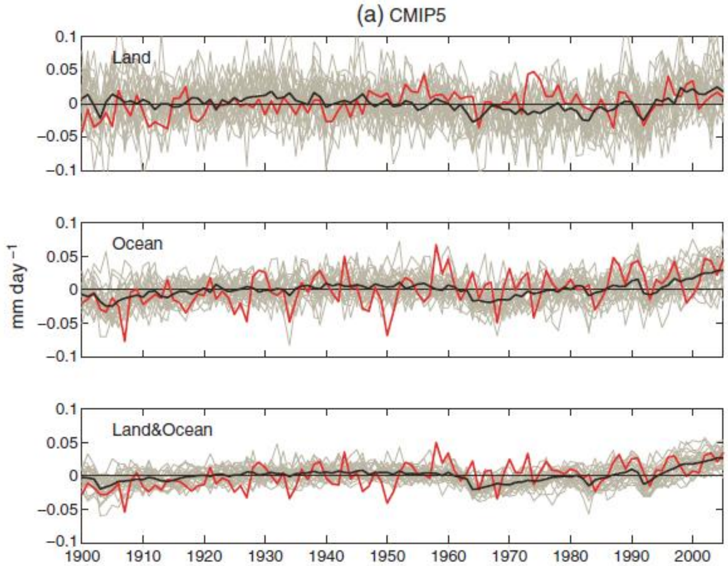

Fig. 3 Global averages over land, oceans and all areas from CMIP5 coupled-model precipitation (grey lines), the model mean (thick black line) and reconstruction (thick red line).

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